MEMO

TO: Matthew Dyrdahl, AICP, CTP, LCI & Team, Alta Planning + Design
FROM: Jessica Schoner, PhD; Brian Almdale, MUPP; Rachel Thompson Panik; Rebecca Sanders, PhD RSP2B,
DATE: 2023-10-02
RE: Appendix A High Injury Network Analysis Report
PROJECT: P018 MnDOT Vulnerable Road User Safety Assessment

Executive Summary

High injury networks (HIN) are a simple and effective tool for identifying concentrations of severe crashes to prioritize. They strike a balance between a reactive and proactive approach by identifying not only high-crash hotspots, but also clusters of single or small numbers of crashes that occur in close proximity to one another and often share risk factors. The clustering approach provides a better understanding of the role of particular roadways and roadway risk factors that lead to a more systemic understanding of safety.

MnDOT's Office of Traffic Engineering (OTE) developed a statewide High Injury Network as part of its Vulnerable Road User Safety Assessment (VRUSA). The HIN, alongside other systemic safety resources included in the VRUSA, can help MnDOT prioritize safety improvements and can provide technical assistance to communities looking to improve vulnerable road user (VRU) safety on their local networks.

The HIN was built using standard methods on a dataset containing VRU crashes from 2017—2021. The HIN only represents fatal and injury crashes, and fatal and serious injury crashes are weighted more heavily than minor injury crashes. In larger urban metro areas, where sample sizes allow, separate pedestrian and bicyclist networks were developed and then combined, to better represent the distinct needs of different types of VRUs. In small urban communities and rural areas, all VRU types are combined into a single network since sample sizes are usually smaller.

After several rounds of discussion with MnDOT staff and technical advisory group, the resulting HIN uses a threshold of 5 (combined VRU score) in small urban areas and rural areas, thresholds of 5 (bicyclists) and 7 (pedestrians) in greater MN urban metro areas and the Twin Cities metro outside of Minneapolis and St. Paul, and 7 (bicyclists) and 12 (pedestrians) within the cities of Minneapolis and St. Paul. This yields about 352 miles of HIN statewide, or about 0.2% of the state's overall road mileage.

The HIN captures about 30% of the state's total VRU crashes. This amount varies by year, mode, and severity. A smaller share of crashes during pandemic years (2020 and 2021) are on the HIN.

Nearly 33% of pedestrian and other VRU crashes are on the HIN, compared with only 26% of bicyclist crashes. Over 35% of serious injury crashes are on the HIN.

The HIN within Minneapolis and St. Paul captures nearly 50% of VRU crashes, but only about 2% of rural VRU crashes are on the HIN. Variations by geography reflect the general urban character of VRU crashes in general – about 75% of all VRU crashes happen in the Twin Cities metro region.

VRU crashes at signal-controlled intersections are best captured by the HIN, with 49% of all severities and 59% of severe crashes on the HIN. Other location types (unsignalized intersection, midblock) have lower concentrations on the HIN.

The HIN's spatial distribution reflects the underlying inequities in traffic crashes. VRU crashes are overrepresented in lower income and majority POC neighborhoods, and the HIN follows this pattern with greater concentrations of HIN in these areas.

The HIN is one of many tools to assist MnDOT and local agencies with planning and engineering for VRU safety. The HIN itself can help communities identify segments with the greatest concentration of crashes needing further investigation and safety improvements. Communities may also access the underlying sliding windows data, if they wish to identify their own threshold and local HIN. Systemic and predictive analyses can also be used to screen both the HIN and other streets for risk factors.

Acronyms

AADT	Annual Average Daily Traffic
AADT	Annual Average Daily Traffic
ADA	Americans with Disabilities Act
BIL	Bipartisan Infrastructure Law
DPS	Department of Public Safety
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
GIS	Geographic Information System
HIN	High Injury Network
HIN	High Injury Network
KA	Killed of severely injured
LRS	Linear Referencing System
MMUCC	Model Minimum Uniform Crash Criteria
MN	Minnesota
MnDOT	Minnesota Department of Transportation
MSI	Most severely injured
MSP	Minneapolis—St. Paul
MV	Motor Vehicle
OTE	Office of Traffic Engineering
Ped	Pedestrian
SPACE	Suitability of Pedestrian and Cyclist Environment
SSA	Safe System Approach
TAMS	Transportation Asset Management System
TCMA	Twin Cities (Minneapolis—St. Paul) Metropolitan Area
USDOT	US Department of Transportation
VPD	Vehicles per day
VRU	Vulnerable road user
VRUSA	Vulnerable Road User Safety Assessment

Table of Contents

Introduction & Purpose

The Bipartisan Infrastructure Law (BIL), passed in 2021, created a new requirement for state departments of transportation to conduct a Vulnerable Road User Safety Assessment (VRUSA) every five years. Anchored in the Safe System Approach (SSA), this assessment must use a data-driven process to identify high risk areas and incorporate equity and demographics into the analysis. Official guidance[1] around this new Vulnerable Road User Safety Assessment recommends the use of High Injury Network, predictive, and/or systemic analysis to identify high risk areas.

There are many established ways to examine crashes to better understand traffic safety patterns. Hotspot analyses have long been used to address high crash locations by retrospectively identifying the greatest concentration of reported crashes over a determined period of time. Hotspot analysis is a valuable method to visualize locations with historic crash issues, but it is less effective at identifying locations with higher crash risk. For example, a wide arterial with a 45-mph posted speed limit, high traffic volumes, no bike facility, and few trip-attracting land uses may not have any reported bike crashes. However, the roadway and operational characteristics of that arterial are associated with higher bicycle crash risk. The absence of crashes is therefore not a reflection of low crash risk, but a reflection of lack of exposure that hotspot analyses cannot adequately convey. Additionally, hotspots may be less effective for analyzing bicyclist safety if crash frequencies are low due to geographic sparsity, which can exacerbate issues related to regression to the mean.

High injury networks strike a balance between entirely retrospective and entirely proactive/predictive methods. Using spatial patterns of crash history, a High Injury Network identifies areas on the road network where crashes have been concentrated in sequence. A stretch of arterial roadway with crashes occurring every other intersection might not show up on a traditional hotspot analysis because no one location has multiple crashes happening in the same place. However, the pattern of crashes all along the corridor suggests a larger safety issue. Further, the entire corridor likely shares similar characteristics that could be addressed systemically – even the intersections along the corridor that have not yet had crashes.

To improve the safety of vulnerable road users in the state of Minnesota and partially satisfy the new VRUSA requirements, the Minnesota Department of Transportation's (MnDOT) Office of Traffic Engineering (OTE) commissioned a Vulnerable Road User Safety Assessment, including development of a High Injury Network for the state, among other analyses. While bicyclists and pedestrians are different roadway users, use different infrastructure in many places, and have

---

[1] FHWA Memorandum, "Vulnerable Road User Safety Assessment Guidance". https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-10/VRU%20Safety%20Assessment%20Guidance%20FINAL_508.pdf

different safety concerns, both bicyclists and pedestrians are vulnerable roadway users that are disproportionately likely to be killed or severely injured in the transportation system.

This report describes the process by which a statewide High Injury Network was built, and the results of that High Injury Network analysis. The High Injury Network was built from a standard sliding windows analysis, which measures severity-weighted crash density by mode along segments on the network. This section of the analysis spans all vulnerable road users, including bicyclists, pedestrians, and other personal conveyances.

The rest of the report is structured as follows: First, an overview of the crash data is presented, followed by basic descriptive summaries of the crash data. Next, we describe methodological trade-offs and decisions for High Injury Network analysis, including the decisions that guided the development of this HIN. Finally, we present the resulting High Injury Network for the state of Minnesota, along with accompanying descriptive analysis of the HIN.

Data Overview

Crash Data

Crash, party, and vehicle data were provided to the consultant team includes reported crashes from 2016 through 2021 for crashes for all modes (pedestrians, bicyclists, and motorists). The statewide High Injury Network (HIN) analyzed the five most recent years of crash data available at the time the project began: 2017-2021, Other VRUSA analyses used different time periods within this dataset; these are documented elsewhere.

All crash data were processed by Safe Streets Research & Consulting ("Safe Streets") and loaded into a Postgres database for additional analysis. The crash, party or vehicle, and person or victim tables have a relational structure, which is common for storing crash data. For every reported crash, there is one record in the crash table. The party/vehicle and person/victim tables contain information for all the primary "actors" and their respective "vehicle" involved in the crash and has a many-to-one relationship – i.e., all relevant party records are matched via a case identification number to the one crash record. The party and victim tables contain information for each primary person and their "vehicle" (if applicable) such as age, sex, pre-crash action, injury severity, and vehicle characteristics. Figure 1 illustrates this relational structure. Parties are classified by the mode of travel or type of vehicle being used. Three of the eight categories are applicable to the VRUSA: mode 5 (pedestrian), mode 6 (bicyclist), and mode 8 (other personal conveyance).

The database we received included all reported crashes for the specified years (2016—2021). However, the scope and methodology of this study necessitated filtering this dataset. Our exclusion criteria were defined by mode(s) involved in the crash and location-based characteristics.

Motorist-only (non-VRU) crashes

For the purpose of the VRUSA, FHWA defines VRU as a nonmotorist with a person code attribute in the Fatality Analysis Reporting System (FARS) equivalent to pedestrian, bicyclist, other cyclist, or other personal conveyance. FHWA further clarifies that VRUs include highway workers on foot in a work zone and exclude motorcyclists.[2] Therefore, we removed crashes that only involved motorists (i.e., did not include person type 5, 6, or 8). We did not attempt to remove highway worker or unintended pedestrian crashes (e.g., crashes involving a driver who has exited their vehicle after breaking down on the highway).

Crashes in which a person was using a scooter or other mobility device (e.g., shared e-scooter or ADA assistive device) are classified within the data as "Other personal conveyance". Many of these crashes – especially those involving someone using a wheelchair or other assistive scooter or device – are more accurately described as "pedestrian" crashes, for the purposes of this analysis. However, this category of "other personal conveyance" crashes includes a broad range of user types that the reporting officer is otherwise unable to categorize, some of which are considered vulnerable road users (people using e-scooters or assistive devices), and some of which are not (e.g., tractors). Indeed, the consultant team read one crash report in which the officer categorized the party as "other personal conveyance" and explained in the narrative that the involved vehicle was actually an airplane.

[2] FHWA Memorandum, "Vulnerable Road User Safety Assessment Guidance". https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-10/VRU%20Safety%20Assessment%20Guidance%20FINAL_508.pdf

Crash Record

ACCN	ACCDAY	LIGHT
161720219	Wednesday	Daylight
160040017	Sunday	Dark (Street Lights On)

ACCN
1:N

Vehicle/Unit Record

ACCN	RVN	VEHTYPE
161720219	1	Pickup
161720219	2	Pedestrian
160040017	1	Passenger Car
160040017	2	Bike

ACCN
RVN
1:N

Person Record

ACCN	RVN	RVP	PTYPE	UNITPER	INJSEV
161720219	1	1	Driver	Motor Vehicle in Transport	No Apparent Injury
161720219	1	2	Passenger	Motor Vehicle in Transport	No Apparent Injury
161720219	2	3	Non-Motorist	Pedestrian	Suspected Serious Injury
160040017	1	1	Driver	Motor Vehicle in Transport	No Apparent Injury
160040017	2	2	Non-Motorist	Bicycle	Suspected Minor Injury

Note: ACCN and RVN uniquely identify vehicles in the database.

Figure 1. Crash Database Schema

We made a targeted effort to categorize “other personal conveyance” crashes based on their likelihood of having been a VRU.

- Other personal conveyance crashes in which the narrative mentions various permutations of the words “walk”, “cycle”, “wheelchair”, “scooter”, and other VRU-related keywords were kept as likely VRU crashes.
- Crashes in which the narrative mentions farm or other road equipment, such as “tractor”, “horse”, or “combine”, were excluded as likely not VRU for the purpose of this study.
- The remainder that could not readily be classified were also kept in the study as “other personal conveyance” crashes.

As stated in the 2019 Pedestrian Safety Analysis, a long-term solution to facilitate routine analysis of scooter involvement in crashes in Minnesota would be to update the crash form with a field to indicate the type of scooter involvement (e.g., e-scooter, kick-scooter, ADA assistive device, moped scooter) and retrain officers to utilize the new field to record accurate and detailed information for more streamlined analysis.

Inapplicable or missing geo-locations

As this study relied heavily on geospatial processing and analysis, crashes with missing geo-location data were excluded – with some exceptions. A small number of pedestrian crashes were missing geo-location data in MnDOT’s main crash database, but had previously been assigned corrected location data as part of MnDOT’s Statewide Pedestrian Crash Analysis study. We migrated this corrected geo-location data to the current project dataset. This affected fatal and serious injury pedestrian crashes from 2016—2019 which had previously been assigned corrected geo-location information. Pedestrian crashes from 2020—2021 and all bicyclist crashes with missing geo-location information were excluded from the analysis.

Crashes that were reported to have occurred in a parking lot were excluded since this study focused on roadways.

Crashes that occurred more than 300 feet from any street were excluded, as were crashes that occurred along private roadways.

Injury Severity Assignment

Crashes in the dataset were assigned a global severity variable that represented the most seriously injured (MSI) party. Usually, the most seriously injured party is also the most vulnerable road user; however, there are rare exceptions. We identified the most seriously injured VRU within each crash and assigned a VRU-specific crash severity to each crash. Since this study focuses exclusively on VRUs, using the victim-level severity helps improve accuracy of summarizing injury severities as they relate to VRU safety and risk factors. It should be noted that the San Francisco Department of Public Health has conducted extensive research and has documented reporting errors related to mis-coded injury severities, particularly for severe injuries[3], suggesting a need for some fluidity when discussing minor and serious injuries. This analysis does not have access to hospital records to verified injury severities stored in the crash data, so the results in this document reflect the best available data at the time.

For reference, the injury severities recorded in the crash data and summarized in this analysis are defined as followed:

- **K - Fatal:** A fatal injury is any injury that results in death within 30 days after the motor vehicle crash in which the injury occurred. If the person did not die at the scene but died within 30 days of the motor vehicle crash in which the injury occurred, the injury classification should be changed from the injury previously assigned to “Fatal Injury”
- **A – Suspected Serious Injury:** An incapacitating injury is any injury, other than a fatal injury, which prevents the injured person from walking, driving or normally continuing the activities the person was capable of performing before the injury occurred. This category includes:
  - severe lacerations
  - broken or distorted limbs
  - skull or chest injuries
  - abdominal injuries
  - unconsciousness at or when taken from the accident scene
  - unable to leave the accident scene without assistance
- **B – Suspected Minor Injury:** A minor injury is any injury that is evident at the scene of the crash, other than fatal or serious injuries. Examples include:
  - lump on the head
  - abrasions, bruises
  - minor lacerations (cuts on the skin surface with minimal bleeding and no exposure of deeper tissue/muscle)
- **C – Possible Injury**: A possible injury is any injury reported or claimed which is not a fatal, suspected serious, or suspected minor injury. Possible injuries are those which are reported by the person or are indicated by their behavior, but no wounds or injuries are readily evident. Examples include:
  - momentary loss of consciousness
  - claim of injury
  - limping, or complaint of pain or nausea.
- **O – Property Damage Only**: Crash where only property is damaged. No injuries resulted from the crash.

There are known variations within MnDOT’s crash data over time as they relate to injury severity definitions. DPS’s reporting forms were updated for compliance with the Model Minimum Uniform Crash Criteria (MMUCC) and for electronic reporting capabilities, with the new system going live at the beginning of 2016. This shift updated the description of crash severities from “Serious Injury” and “Minor Injury” to “*Suspected* Serious Injury” and

---

[3] https://www.visionzerosf.org/wp-content/uploads/2021/11/Severe-Injury-Trends 2011-2020 final report.pdf

"*Suspected* Minor Injury" (emphasis added). The crash data in 2016 showed an initial surge in injuries classified as serious injuries that would have been classified as minor injuries in 2015 or earlier. Over time, severity rates stabilized as officers received more training and had more experience with the new system. Year-to-year severity comparisons from about 2015 to 2017 may be affected by this shift. Because the High Injury Network pools data *across years*, rather than comparing *between years*, this analysis should be largely unaffected by the change.

Roadway and Contextual Data

High Injury Network analysis primarily relies on spatially processing crash history along a road network. Therefore, minimal – if any – roadway attributes are needed for this type of analysis. We joined High Injury Network analysis results to MnDOT's Trunk Highway network to be able to identify which segments of the HIN are on state-owned roadways. We also joined the HIN to MnDOT's Suitability of the Pedestrian and Cycling Environment (SPACE) dataset to be able to evaluate the HIN through this lens. Crash and HIN segment data were joined to these layers spatially.

Crash Data Summary

This section briefly summarizes crashes by mode, year, and severity for VRU crashes that are included in the sliding windows analysis.

Crash Mode

Table 1 shows the distribution of VRU crashes by mode and severity that were considered for the HIN analysis. Among the VRU crashes considered for High Injury Network analysis, 55% were pedestrian crashes, 39% bicyclist crashes, and the remainder were other personal conveyance (including those flagged as likely VRU, and excluding those flagged as farm equipment). As discussed in the next section, only fatal, serious injury, and minor injury crashes were ultimately included in the final High Injury Network, so the subtotal of included crashes is also shown in the table.

Table 1. Number of crashes by mode and severity, 2017—2021.

Mode	Fatal and Serious Injury	Minor Injury	Possible Injury and PDO (excluded)	Total Crashes	Total Included (KAB only)	Percentage of All Crashes*	Percentage Included* (KAB only)
Bicyclist	302	1,431	1,133	2,866	1,733	39%	38%
Pedestrian	981	1,675	1,395	4,051	2,656	55%	59%
Other - Personal Conveyance	29	89	272	390	118	5%	3%
Total	**1,312**	**3,195**	**2,800**	**7,307**	**4,507**	**100%**	**100%**

**Percentages may not sum to 100% due to rounding error*

Injury Severity

Table 2 shows the crash distribution by injury severity for all VRUs. Pedestrians have the largest share of fatal crashes at 5%, followed by other VRU crashes. Most bicyclist crashes are minor injury and possible injury crashes, although 9% are severe injury crashes. Other personal conveyance crashes are much more likely to be property damage only crashes than our other VRU-identified crashes – that may reflect the composition of modes within this "catch all" category that has neither been confirmed VRU nor confirmed non-VRU/farm equipment.

Table 2: All Study Crashes by Severity, 2017 – 2021

Mode		Fatal (K)	Severe Injury (A)	Minor Injury (B)	Possible Injury (C)	Property Damage Only (O)	*Total*
Bicyclist	Count	41	261	1,431	919	214	2,866
	Percentage	1.4%	9.1%	49.9%	32.1%	7.5%	100.0%
Pedestrian	Count	221	760	1,674	1,238	158	4,051
	Percentage	5.5%	18.8%	41.3%	30.6%	3.9%	100.0%
Other - VRU	Count	5	15	58	51	32	161
	Percentage	3.1%	9.3%	36.0%	31.7%	19.9%	100.0%
Other – Personal Conveyance	Count	0	9	31	20	169	229
	Percentage	0.0%	3.9%	13.5%	8.7%	73.8%	100.0%
Total	**Count**	**267**	**1,045**	**3,195**	**2,228**	**572**	**7,307**
	Percentage	**3.7%**	**14.3%**	**43.7%**	**30.5%**	**7.8%**	**100.0%**

Year

Table 3 describes the distribution of VRU crashes by year, including the number of Fatal and Serious Injury crashes (KA), and the shares of total crashes and KA among each VRU mode per year. Table 3 shows several trends. First, pedestrian crashes make up the largest share of all VRU crashes each year and the largest share of KA crashes each year. Each year, pedestrian crashes are more likely than other VRU modes to result in death or serious injury ("% KA within Mode and Year"). Both of these trends indicate that pedestrians are overburdened for severe and fatal injuries in the Minnesota statewide transportation system.

Another trend is that, while the modal composition from year to year remains fairly stable, the severity across all VRU modes has increased in recent years. Bicyclist crashes have comprised about 36% to 42% of all yearly VRU crashes, and pedestrian crashes represent about 53% to 59%. The severity rate for bicyclist crashes peaked in 2020, with just over 14% of bicyclist crashes resulting in a severe outcome. Pedestrian crashes appeared to be decreasing in severity prior to the 2020 COVID-19 pandemic, but the severity rate increased in 2020 and again in 2021. The pandemic-affected years show lower totals of crashes overall, but the decreases appear to be the result of reductions in non-severe crashes. These severity patterns mimic national trends, where empty, over-capacity roads encouraged unsafe speeds and an increase in high motorist speed crashes for all road users.

It is possible that these pandemic-related severity patterns could correlate with pandemic-related geospatial differences. Travel behavior shifted as more people worked from home or stayed home for leisure activities. However, the number of crashes in 2020 and 2021 is too small to perform a separate High Injury Network analysis to verify the potential effects of the pandemic on the final HIN. We recommend further analysis once additional years of data are available to understand whether and how the pandemic has shifted spatial patterns for vulnerable road users.

Table 3: All Crashes, By Year and Mode, 2017 – 2021

Year and Mode	# Crashes	# KA Crashes	% Yearly Crashes	% Yearly KA Crashes	% KA within Mode and Year
2017	1,724	305	100.0%	100.0%	17.7%
Bicyclist	720	61	41.8%	20.0%	8.5%
Pedestrian	943	239	54.7%	78.4%	25.3%
Other - VRU	20	3	1.2%	1.0%	15.0%
Other – Personal Conveyance	41	2	2.4%	0.7%	4.9%
2018	1,593	262	100.0%	100%	16.4%
Bicyclist	576	56	36.2%	21.4%	9.7%
Pedestrian	931	203	58.4%	77.5%	21.8%
Other - VRU	30	2	1.9%	0.8%	6.7%
Other – Personal Conveyance	56	1	3.5%	0.4%	1.8%
2019	1,654	246	100.0%	100%	14.9%
Bicyclist	642	65	38.8%	26.4%	10.1%
Pedestrian	906	175	54.8%	71.1%	19.3%
Other - VRU	44	4	2.7%	1.6%	9.1%
Other – Personal Conveyance	62	2	3.7%	0.8%	3.2%
2020	1,114	236	100.0%	100%	21.2%
Bicyclist	433	61	38.9%	25.8%	14.1%
Pedestrian	617	170	55.4%	72.0%	27.6%
Other - VRU	26	3	2.3%	1.3%	11.5%
Other – Personal Conveyance	38	2	3.4%	0.8%	5.3%
2021	1,222	263	100.0%	100%	21.5%
Bicyclist	495	59	40.5%	22.4%	11.9%
Pedestrian	654	194	53.5%	73.8%	29.7%
Other - VRU	41	8	3.4%	3.0%	19.5%
Other – Personal Conveyance	32	2	2.6%	0.8%	6.2%
Total	**7,307**	**1,312**			

High Injury Network Methodology

High Injury Networks are typically built using a process called sliding windows analysis, which helps detect patterns of crashes happening in sequence. A sliding windows analysis calculates linear crash densities (often weighted by injury severity) for each mode separately. The sliding windows analysis consists of a virtual window of a predetermined length that is moved along the street network at predetermined step lengths and aggregates crashes that are within each window (see Figure 2).

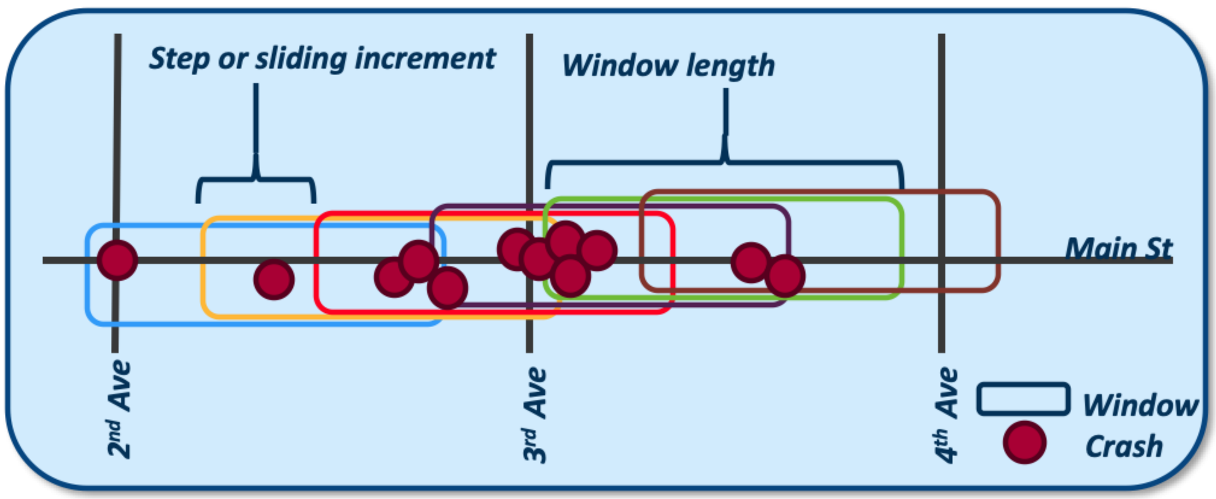

Figure 2. Sliding windows process to measure crash density along a network.

Two different window lengths were used based on the SPACE urban/rural designations as a means to account for different crash densities, roadway characteristics, and land use across the urban—rural gradient. Large metropolitan urban areas (e.g., Minneapolis—St. Paul, Rochester, Duluth, St. Cloud, Fargo-Moorehead, Mankato), one-mile window lengths and 1/10th-mile step increments were used in this analysis. For smaller urban communities (e.g., Bemidji, Brainerd, Alexandria, Willmar, Redwing, etc.) as well as rural areas, two-mile window lengths and ¼-mile step increments were used.

Additionally, only fatal (K), severe injury (A), and minor injury (B) crashes were included in the sliding window analysis and HIN development process. This decision was made to prioritize locations that have a history and high concentration of crashes that resulted in death or injury. The Safe System Approach pushes us to prioritize fatal and serious injury crashes. We additionally included minor injury crashes for several reasons, including:

1) The geographic sparsity of vulnerable road user crashes, especially in smaller urban communities and urban areas, leads to sparse or patchy results in a High Injury Network.
2) Misclassification between serious injury and minor injury crashes in police reports is common.
3) Individual characteristics like age and frailty can influence how severe an injury outcome is.

To maintain an appropriate emphasis on life-altering crashes, we weighted fatal and serious injury crashes more heavily in the analysis (3:1 weighting).

Threshold Determination

HINs are a blend of art and science, needing to be large enough to be meaningful, but not so large as to be meaningless. This balance is even more pronounced for larger HINs, e.g., at the regional or statewide level, that cover vastly different land use patterns and geography types. To strike this balance, each mode-specific HIN is produced by an initial determination of a minimum threshold for the weighted crash value of segments to be included in the HIN, followed by review of the distribution of crashes for each mode along the relevant HIN and the percentage of the network that is along that HIN. If necessary, the threshold is adjusted to achieve the sought-after balance described above.

- Using a **high threshold** will make a high injury network smaller (fewer miles), focusing only on the places that have had many fatal and injury crashes.
- Using a **low threshold** will make a high injury network larger (more miles), including places that may have only had one or two fatal and injury crashes.
- Using **too low of a threshold** produces networks that are not meaningfully targeted at fatal and injury crashes.

Generally speaking, with fatal and serious injury crashes weighted at 3 and minor injury crashes weighted at 1, the lowest possible threshold that may still reflect spatial patterns is 5. With a score of 5, a segment will have had at least 2-3 crashes within the window size (1-2 miles) over the previous 5 years, with at least 1-2 of them resulting in death or serious injury.

In addition to being tailored to each mode, thresholds may vary by geography. Denser, larger urbanized areas have more VRU crashes in general and have higher scores on average. Smaller urban areas and rural areas have fewer VRU crashes and lower scores on average. Choosing a single threshold to use across all geography types (“severe injury density” approach) results in a HIN that is heavily concentrated in denser, larger urbanized areas. It aggressively targets the highest concentrations of fatal and injury crashes. Choosing variable thresholds based on geography type (“geographic balance” approach) results in a HIN that has broad coverage across many contexts, though coverage may not be proportionate to the severity of safety problems.

HIN Considerations and Use

There are benefits and drawbacks to each approach, and the best approach depends heavily on the intended purpose or uses of the HIN. For a city with a dedicated pot of safety funding, the severe injury density approach may lead them to make more efficient investments by targeting the highest concentrations of severe crashes first. In the State DOT context, where there is no single dedicated funding source and the HIN must serve many purposes, the geographic balance approach helps ensure the ability to make progress on safety across the state and with many local partner agencies. These benefits and trade-offs are described in greater detail in Table 4.

Table 4. How should the HIN's intended use inform its definition?

Potential Uses for HIN	Threshold Recommendation	Relationship between HIN and predictive or systemic analysis	Pros/Cons of Geographic Balance Strategy	Pros/Cons of Severe Injury Density Strategy	Conclusions
Prioritization on agency's own roads	• A higher threshold helps the agency identify and target the highest priority areas.	• Use HIN to identify highest priorities based on crash history as the "backbone" of the safety plan. These are sites that have known, repeated VRU safety problems. • Predictive or systemic results could in theory be used to screen for additional priorities within or beyond the HIN, as roadway data attributes allow.	• PRO: Recognizes the reality that the agency must invest and improve safety across the whole state, not just in one area. • PRO: Provides opportunities for all districts to work on VRU safety. • CON: Areas with greater numbers of fatalities and severe injuries may receive proportionally less funding, which may impact the speed at which problems are ultimately addressed.	• PRO: More directly works toward the goal of zero deaths and serious injuries by prioritizing areas with the highest raw numbers. • CON: Areas with smaller, sparser populations, even with high-risk roads, may be systematically disadvantaged because they cannot compete with larger, denser areas. • CON: Concentrating priorities in a single district may be politically infeasible	• HIN plays a larger role for this use than other uses, and pred/sys results play a smaller role • Choose a higher threshold (small HIN) to focus on the highest priorities on state roads • Some amount of geographic balancing is likely necessary
Project scoping on agency's own roads	• A lower threshold allows the agency to identify VRU safety needs in places where other, non-safety projects are scheduled	• Predictive or systemic analyses can play a significant role in scoping, since projects are evaluated on a case-by-case basis. Co-location with the HIN may be one of many factors to identify VRU safety needs.	• PRO: Provides opportunities for VRU safety needs to be added to projects statewide, including in lower density areas • CON: May dilute the power of being on the HIN if low-scoring areas are included	• PRO: Helps ensure that safety needs are identified in the highest priority areas. • CON: Areas with smaller, sparser populations, even with high-risk roads, may be systematically disadvantaged because they cannot compete with larger, denser areas. • CON: Concentrating priorities in a single district may be politically infeasible	• HIN relatively less important, and pred/sys can play a larger role. • Higher HIN threshold can be appropriate for this use with or without geo balancing, given complementary use of pred/sys results.
Funding allocation for other agencies' roads	• A lower threshold may be appropriate to evaluate safety projects statewide by other agencies. • A higher threshold helps direct limited funds to the highest safety priorities.	• Predictive or systemic analyses can play a significant role in scoping, since projects are evaluated on a case-by-case basis. Co-location with the HIN may be one of many factors to identify VRU safety needs. • All of this assumes that HIN status is NOT a requirement for state funding applications.	• PRO: Provides opportunities for jurisdictions throughout the state to apply for funding based on statewide analysis • CON: Areas with greater numbers of severe injuries may receive proportionally less funding, which may impact the speed at which problems are ultimately addressed	• PRO: More directly works toward the goal of zero deaths and serious injuries by targeting funding to the areas with the highest raw numbers • CON: Areas with smaller, sparser populations, even with high-risk roads, may be systematically disadvantaged because they cannot compete with larger, denser areas. • CON: Concentrating investment opportunities in just one area may be politically infeasible	• HIN relatively less important and pred/sys can play a larger role • It may be impossible to choose a threshold and a strategy that are agreeable to all stakeholders, since these choices influence who would receive funding
Technical support for other agencies	• A lower threshold helps maximize the number of agencies that have HIN on their local networks. • Providing underlying scoring data can help agencies refine a local HIN if desired.	• In theory, predictive and systemic results as well as underlying scoring data can be useful resources for local agencies. • However, if local agencies are pursuing funding that requires projects be on the HIN, then the role for the other analysis methods is diminished.	• PRO: Helps ensure no one agency is overwhelmed with too many priorities. • PRO: Helps ensure more agencies have at least 1-2 priority segments they can focus on. • PRO: The agencies most likely to benefit from a geo balance strategy are the least likely to already have their own HIN. • CON: May dilute the power of being on the HIN if low-scoring areas are included.	• PRO: For all agencies outside of MSP, inclusion on the statewide HIN may communicate a very high VRU safety need. • CON: Areas with smaller, sparser populations, even with high-risk roads, may be systematically disadvantaged because they cannot compete with larger, denser areas and may not have any HIN within their boundaries. • CON: The areas with the most HIN mileage already have their own HINs.	• While pred/sys and underlying scoring data are valuable, HIN status may be a requirement for some funding types (e.g., SS4A) • A "big tent" geographically balanced network provides the most opportunities for local agencies to focus on VRU safety – even if it includes lower or moderate-scoring areas

MnDOT intends for this HIN to provide technical support to local partner agencies, and recognizes that the HIN is one of many tools and resources available for prioritizing investment, scoping projects, and allocating funds. After discussion with MnDOT and stakeholders, and testing and receiving feedback from MnDOT on various thresholds, the project team developed this High Injury Network using the geographic balance approach.

HINs can make for a useful communication tool because the data are reduced to a simple binary: streets on and off the high injury network. At the same time, this data reduction masks variation, so the underlying granular sliding windows data may be more useful for internal prioritization procedures or for providing technical assistance. Unlike intersection hotspot analysis, sliding windows analysis and HINs can identify entire corridors that have experienced patterns of crashes, leading to the possibility of systemic treatments. The High Injury Network will be analyzed and described further in this memo, and the granular underlying data will be made available for future work or for providing technical support to local agencies.

Sliding windows results

Note that all roadway mileage estimates are just that – estimates. Our dataset included dual centerlines for divided roadways. Total mileage may not match published statewide totals. But the approximate distribution should be similar, as should the order of magnitude.

Table 5 shows the distribution of network mileage by sliding windows score. The distribution is shown for five geographic groupings across the state, derived from MnDOT's SPACE dataset's "urban" variable and the city boundaries of Minneapolis and St. Paul.

- Cities of Minneapolis and St. Paul
- Remainder of Twin Cities metropolitan area
- Other metropolitan and large urban areas in the state (e.g., Duluth and surrounding metro area)
- Small urban areas (e.g., Alexandria, Bemidji)
- Rural areas

This score represents all vulnerable road user types (ped, bike, and other) and spans data from 2017–2021. Crashes are weighted by severity, with fatal and serious injury crashes scoring 3 points, minor injury crashes scoring 1 point, and lower severity crashes excluded from the High Injury Network analysis.

Table 5: Approximate network mileage of combined VRU scores by geography (dual carriageways are double-counted so mileage totals may not match centerline miles)

Score	TCMA - Minneapolis and St. Paul		TCMA - Other cities		Greater MN metro areas		Small urban communities		Rural areas	
	N	%	N	%	N	%	N	%	N	%
0	1,079	53.3%	10,244	84.3%	1,844	83.3%	11,898	92.6%	118,669	99.4%
1-2	386	19.0%	1,067	8.8%	203	9.2%	541	4.2%	270	0.2%
3-5	258	12.7%	679	5.6%	123	5.6%	336	2.6%	403	0.3%
6-8	112	5.5%	116	1.0%	26	1.2%	57	0.4%	17	<0.1%
9-11	46	2.3%	26	0.2%	16	0.7%	13	0.1%	2	<0.1%
12-14	47	2.3%	13	0.1%	0	<0.1%	0	0.0%	0	0.0%
15-17	37	1.8%	4	<0.1%	0	<0.1%	0	0.0%	0	0.0%
18-20	31	1.5%	2	<0.1%	1	<0.1%	0	0.0%	0	0.0%
21-29	21	1.0%	3	<0.1%	0	0.0%	0	0.0%	0	0.0%
30+	9	0.5%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total	*2,026*	*100.0%*	*12,154*	*100.0%*	*2,213*	*100.0%*	*12,845*	*100.0%*	*119,361*	*100.0%*

From this table we see further evidence of patterns already identified in the previous chapter. Vulnerable road user crashes have the greatest concentration within the most densely, heavily urbanized areas of the state. Nearly half of Minneapolis and St. Paul's road network has a score of 1 or greater, indicating at least one minor injury (or worse) crash over the previous 5 years. In the rest of the Twin Cities metro and in other metro and large urban areas around the state, this figure is just over 15%. In smaller urban areas, less than 10% of road miles have seen one or more fatal or injury crashes in the past 5 years. And in rural areas, which represent over 80% of the state's network, segments with a vulnerable road user fatal or injury crash history comprise just over one half of one percent (0.6%). This table underscores why we recommended a methodology that sets distinct thresholds for different geography types – to ensure that the HIN is not exclusively or primarily clustered in just one area, and that cities, counties, and districts across the state can identify opportunities to work toward reducing and eliminating vulnerable road user traffic deaths.

The next two tables show this same distribution separated by mode – first, for pedestrians and other vulnerable road users, then for bicyclists. The modal distributions are largely similar, with greater concentrations of fatal and injury crashes within denser, more urbanized areas. Pedestrian and other vulnerable road user crashes are more numerous and widespread than bicyclist crashes. With both Table 6 and Table 7, the distribution of scores for smaller urban areas is between that for larger urban areas (excluding Minneapolis and St. Paul) and rural areas. For bicyclist crashes, however, the distribution for small urban areas is very similar to that of rural areas, with over 96% of the network in small urban communities having had zero bicyclist fatal or injury crashes over the previous 5 years. Note that High Injury Networks do not control for bicyclist or pedestrian volumes; an area with 0 crashes is not necessarily safe for VRUs.

Table 6: Pedestrian and other VRU scores by geography

Score	TCMA – Minneapolis and St. Paul		TCMA – Other cities		Greater MN metro areas		Small urban communities		Rural areas	
	N	%	N	%	N	%	N	%	N	%
0	1,254	62.0%	11,006	90.5%	1,963	88.6%	12,228	95.2%	118,938	99.6%
1-2	308	15.2%	612	5.0%	138	6.2%	297	2.3%	134	0.1%
3-5	243	12.0%	436	3.6%	88	4.0%	283	2.2%	280	0.2%
6-8	78	3.8%	76	0.6%	19	0.9%	35	0.3%	8	<0.1%
9-11	52	2.5%	17	0.1%	5	0.2%	2	<0.1%	0	<0.1%
12-14	39	1.9%	3	<0.1%	0	<0.1%	0	0.0%	0	0.0%
15-17	21	1.0%	2	<0.1%	1	<0.1%	0	0.0%	0	0.0%
18-20	16	0.8%	1	<0.1%	0	0.0%	0	0.0%	0	0.0%
21-29	7	0.4%	3	<0.1%	0	0.0%	0	0.0%	0	0.0%
30+	7	0.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total	*2,025*	*100.0%*	*12,156*	*100.0%*	*2,214*	*100.0%*	*12,845*	*100.0%*	*119,360*	*100.0%*

Table 7: Bicyclist scores by geography

Score	TCMA – Minneapolis and St. Paul		TCMA – Other cities		Greater MN metro areas		Small urban communities		Rural areas	
	N	%	N	%	N	%	N	%	N	%
0	1,425	70.4%	10,957	90.1%	1,987	89.8%	12,349	96.1%	119,064	99.8%
1-2	355	17.6%	873	7.2%	158	7.2%	397	3.1%	151	0.1%
3-5	185	9.2%	307	2.5%	68	3.1%	89	0.7%	145	0.1%
6-8	43	2.1%	15	0.1%	0	0.0%	10	0.1%	1	<0.1%
9-11	10	0.5%	3	<0.1%	0	0.0%	0	0.0%	0	0.0%
12-14	4	0.2%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
15-17	0	<0.1%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
18-20	2	0.1%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total	*2,024*	*100.0%*	*12,155*	*100.0%*	*2,213*	*100.0%*	*12,845*	*100.0%*	*119,361*	*100.0%*

HIN Thresholds and Results

Based on the distribution of scores by geography, conversations with MnDOT and stakeholders, review of draft HINs using various thresholds, and MnDOT's goals for the HIN, our team ultimately recommended the following thresholds:

Table 8: HIN threshold by mode and geography group

Geography group	Window Length	Pedestrian/Other VRU Threshold	Bicyclist Threshold	All VRU Threshold
TCMA - Minneapolis and St. Paul	1 mile	12	7	N/A
TCMA - Other cities	1 mile	7	5	N/A
Greater MN metro areas	1 mile	7	5	N/A
Small urban communities	2 miles	N/A	N/A	5
Rural areas	2 miles	N/A	N/A	5

These thresholds yield the following miles of HIN:

Table 9: Miles of HIN by geography group

HIN	TCMA - Minneapolis and St. Paul		TCMA - Other cities		Greater MN metro areas		Small urban communities		Rural areas		Statewide	
	N	%	N	%	N	%	N	%	N	%	N	%
HIN for all VRU	19	0.9%	7	0.1%	0	0.0%	95	0.7%	20	<0.1%	140	0.1%
HIN for Bike only	23	1.1%	30	0.2%	10	0.4%	0	0.0%	0	0.0%	62	<0.1%
HIN for Ped/ Other only	72	3.5%	64	0.5%	15	0.7%	0	0.0%	0	0.0%	150	0.1%
Any HIN Subtotal	***113***	***5.6%***	***100***	***0.8%***	***24***	***1.1%***	***95***	***0.7%***	***20***	***<0.1%***	***352***	***0.2%***
Non-HIN	1911	94.4%	12,055	99.2%	2,190	98.9%	12,751	99.3%	119,341	>99.9%	148,247	99.8%
Total	2,024	100.0%	12,155	100.0%	2,214	100.0%	12,845	100.0%	119,361	100.0%	148,600	100.0%

Since the purpose of a High Injury Network is to identify clusters or patterns of crashes, it is important to choose a threshold that is high enough to represent a true pattern. We recommend five as the lowest possible threshold for defining a High Injury Network because it implies a minimum of 2-3 fatal and injury crashes to meet or exceed it. In order to reach this minimum threshold in small urban areas and rural areas, we used a longer window length and also combined all VRU crashes into a single HIN category.

We see over 200 miles of HIN within the Twin Cities metro area alone, plus 25 in other large metro urban areas, 95 in smaller urban areas, and 20 in rural areas. Note that crash data on

Tribal lands are typically incomplete in MnDOT's dataset, so the rural HIN may underestimate crash concentrations in rural areas absent this data.

In the Twin Cities, there is a small amount of overlap between pedestrian/other VRU HIN and bicyclist HIN, whereas in other large metro urban areas around the state, we do not see any overlap. The fact that we see different spatial patterns here reinforces the decision to analyze pedestrian and bicyclist crashes separately where data allow.

Descriptive Analysis of Crashes On and Off the HIN

We joined HIN status and sliding window scores back to individual crashes for further analysis.

High Injury Network Patterns Over Time

Table 10 shows how many crashes are on any HIN-identified segments for any mode. Table 11 shows this filtered on fatal and serious injury (K+A) crashes. On average, about 29% of all VRU crashes and 31% of severe VRU crashes are on the HIN, though this varies year to year.

The HIN was defined using 2017–2021 data, so 2016's crashes are an "out-of-sample" test of how well the HIN correlates with crashes in other years; 26% of 2016's VRU crashes and only 20% of 2016's severe VRU crashes are on the HIN. For the pre-pandemic HIN years 2017–2019, roughly 31-33% of VRU crashes and 35 to almost 38% of severe VRU crashes are on the HIN. During the pandemic years (2020–2021), the HIN covers a smaller share of crashes (26% of all severity and 29-31% of severe), indicating that crashes were more dispersed and less clustered than VRU crashes in earlier years.

As previously noted with Table 3, the sample size is too small to compare a pandemic-only version of the HIN to a non-pandemic version, but continuing to monitor these trends as more post-pandemic years of crash data become available will help MnDOT understand the latest evolving patterns.

Table 10: N and % of VRU crashes on and off any HIN by year (note that HIN was developed on 2017--2021 crashes, so 2016 crashes are "out of sample")

Year	Crashes off the HIN		Crashes on the HIN	
	N	%	N	%
2016	1,277	73.9%	452	26.1%
2017	1,184	68.7%	540	31.3%
2018	1,082	67.9%	511	32.1%
2019	1,114	67.4%	540	32.6%
2020	823	73.9%	291	26.1%
2021	900	73.6%	322	26.4%
Total	***6,380***	***70.6%***	***2,656***	***29.4%***

Table 11: N and % of severe (K+A) VRU crashes on and off any HIN by year (note that HIN was developed on 2017--2021 crashes, so 2016 crashes are "out of sample")

Year	KA Crashes off the HIN		KA Crashes on the HIN	
	N	%	N	%
2016	269	80.1%	67	19.9%
2017	197	64.6%	108	35.4%
2018	170	64.9%	92	35.1%
2019	153	62.2%	93	37.8%
2020	168	71.2%	68	28.8%
2021	181	68.8%	82	31.2%
Total	***1,138***	***69.1%***	***510***	***30.9%***

The previous two HIN summary tables included 2016 because 2016 provides an "out-of-sample" check on the HIN. All remaining analyses in this section include only 2017–2021 crashes, since those are the ones used to define the HIN.

HIN Status by Crash Mode and Severity

The HIN is defined by fatal, serious injury, and minor injury crashes, using weights to more heavily emphasize fatal and serious injury crashes. We see varying percentages of crashes on and off the HIN by crash severity, though the pattern is not very intuitive or meaningful. Serious injury crashes have the greatest representation on the HIN, with over 35% of them falling on the HIN (Table 12).

Table 12: N and % of VRU crashes on and off any HIN by crash severity

Injury Severity	Crashes off the HIN		Crashes on the HIN	
	N	%	N	%
Fatal (K)	194	72.7%	73	27.3%
Serious injury (A)	675	64.6%	370	35.4%
Minor injury (B)	2,295	71.8%	900	28.2%
Possible injury (C)	1,509	67.8%	719	32.3%
Property damage only (O)	430	75.2%	142	24.8%
Total	***5,103***	***69.8%***	***2,204***	***30.2%***

Pedestrian and other VRU crashes were more tightly clustered on the network, with nearly 33% of them being on the HIN compared to only 26% of bicyclist crashes (Table 13). Note that this is the entire HIN, not limited by mode (e.g., bicyclist crashes on the bicycle HIN).

Table 13: N and % of VRU crashes on and off any HIN by crash mode

Mode	Crashes off the HIN		Crashes on the HIN	
	N	%	N	%
Bicyclist	2,118	73.9%	748	26.1%
Pedestrian/VRU	2,985	67.2%	1,456	32.8%
Total	***5,103***	***69.8%***	***2,204***	***30.2%***

Among bicyclist crashes in metro, large urban areas, the bicycle HIN best represents the location of serious injury crashes (almost 30% on the network) but overall captures just under 17% of all urban bicyclist crashes (Table 14).

HIN Status by Geography

Table 14: Urban bike crashes on and off the urban bike HIN, by severity

Injury Severity	Crashes off the HIN		Crashes on the HIN	
	N	%	N	%
Fatal (K)	21	84.0%	4	16.0%
Serious injury (A)	138	70.1%	59	29.9%
Minor injury (B)	984	84.4%	182	15.6%
Possible injury (C)	701	85.7%	117	14.3%
Property damage only (O)	152	80.4%	37	19.6%
Total	**1,996**	**83.3%**	**399**	**16.7%**

The pedestrian/other VRU HIN in urban areas does a better job of capturing urban pedestrian/other VRU crashes, with 33% of all severities on the network and nearly 39% of serious injury crashes on the HIN (Table 15).

Table 15: Urban ped and other VRU crashes on and off the urban ped and other VRU HIN, by severity

Injury Severity	Crashes off the HIN		Crashes on the HIN	
	N	%	N	%
Fatal (K)	101	69.2%	45	30.8%
Serious injury (A)	370	61.4%	233	38.6%
Minor injury (B)	1,030	68.6%	472	31.4%
Possible injury (C)	744	64.2%	414	35.8%
Property damage only (O)	193	78.1%	54	21.9%
Total	**2,438**	**66.7%**	**1,218**	**33.3%**

Only about 15% of small urban community and rural area crashes are on the small urban community and rural HINs, though the small urban and rural HIN does a better job of capturing fatal and serious injury crashes in these areas (23% and 20% respectively; Table 16).

Table 16: Small urban community and rural VRU crashes on and off the small urban and rural HIN, by severity

Injury Severity	Crashes off the HIN		Crashes on the HIN	
	N	%	N	%
Fatal (K)	74	77.1%	22	22.9%
Serious injury (A)	196	80.0%	49	20.0%
Minor injury (B)	447	84.8%	80	15.2%
Possible injury (C)	225	89.3%	27	10.7%
Property damage only (O)	128	94.1%	8	5.9%
Total	**1,070**	**85.2%**	**186**	**14.8%**

Across all VRU modes, the Minneapolis and St. Paul HIN captures the greatest share of crashes. Table 17 shows nearly 50% of them falling on the network (which, as Table 9 showed, comprises only 5% of the network mileage). In the rest of the Twin Cities metro, other large metro urban areas, and small urban communities, 16-20% of VRU crashes are on the HIN. Only 2% of rural area crashes are on the rural HIN.

Table 17: N and % of VRU crashes on and off any HIN by geography group

Geography group	Crashes off the HIN		Crashes on the HIN	
	N	%	N	%
TCMA - Minneapolis and St. Paul	1,560	50.2%	1,550	49.8%
TCMA - Other cities	1,963	84.4%	362	15.6%
Greater MN metro areas	510	82.8%	106	17.2%
Small urban communities	732	80.4%	179	19.6%
Rural areas	338	98.0%	7	2.0%
Total	**5,103**	**69.8%**	**2,204**	**30.2%**

Among severe crashes, our HIN does a better job in all geography groups (Table 18).

Table 18: N and % of severe (K+A) VRU crashes on and off any HIN by geography group

Geography group	KA Crashes off the HIN		KA Crashes on the HIN	
	N	%	N	%
TCMA - Minneapolis and St. Paul	193	44.5%	241	55.5%
TCMA - Other cities	337	76.9%	101	23.1%
Greater MN metro areas	69	69.7%	30	30.3%
Small urban communities	139	68.5%	64	31.5%
Rural areas	131	94.9%	7	5.1%
Total	**869**	**66.2%**	**443**	**33.8%**

HIN Status by Location Type

The HIN does a much better job of capturing signalized intersection VRU crashes than crashes at other location types, with 49% of all VRU crashes at signalized intersections and 59% of severe crashes at signalized intersections falling on the HIN (Table 19 and Table 20). These other location types (e.g., midblock or segment locations, with 16%, and unsignalized/stop-controlled intersections, with 22%) are vastly more numerous around the state than signalized intersections; without exposure data, we can't normalize crashes per location or per VRU walking, biking, or rolling there.

Table 19: N and % of VRU crashes on and off any HIN by location type

Crash Location	Crashes off the HIN		Crashes on the HIN		Total	
	N	%	N	%	N	%
Intersection - Signal controlled	1,285	50.8%	1,246	49.2%	2,531	100.0%
Intersection - Partial or all-way stop controlled	1,883	78.1%	528	21.9%	2,411	100.0%
Segment or midblock	1,651	83.6%	325	16.4%	1,976	100.0%
Other or unknown location	284	73.0%	105	27.0%	389	100.0%
Total	**5,103**	**69.8%**	**2,204**	**30.2%**	**7,307**	**100%**

Table 20: N and % of severe (K+A) VRU crashes on and off any HIN by location type

Crash Location	KA Crashes off the HIN		KA Crashes on the HIN		Total	
	N	%	N	%	N	%
Intersection - Signal controlled	141	41.4%	203	58.6%	348	100.0%
Intersection - Partial or all-way stop controlled	296	72.0%	114	28.0%	414	100.0%
Segment or midblock	388	78.9%	105	21.1%	498	100.0%
Other or unknown location	44	67.7%	21	32.3%	65	100.0%
Total	**869**	**66.2%**	**443**	**33.8%**	**1,312**	**100%**

HIN Status by Location Type and Pre-Crash Movement / Action

The following tables (Table 21 and Table 22) show what percentage of all and severe VRU crashes fall on the HIN by crash type, focusing on crash types that have at least 40 fatal and serious injury crashes. The rows are sorted by the total number of fatal and serious injury crashes for each type (not shown in the tables). All crash types with fewer than 40 fatal and serious injury crashes are combined into "Other bicyclist crash type" and "Other pedestrian/VRU crash type."

Among bicyclist crash types, the "Signal - MV Forward - Bike Walk/Cycle Across Traffic/Roadway" crash type has the best representation on the HIN. Thirty five percent of all severity crashes and 48% of severe crashes of this type are on the HIN.

Table 21: N and % of Bicyclist crashes by crash type and location status (among crash types with >=40 K+A bicyclist crashes)

Crash Type	Crashes off the HIN		Crashes on the HIN		Total	
	N	%	N	%	N	%
Stop - MV Forward - Bike Walk/Cycle Across Traffic/Roadway	347	86.1%	56	13.9%	403	100.0%
Signal - MV Forward - Bike Walk/Cycle Across Traffic/Roadway	191	65.2%	102	34.8%	293	100.0%
Other bicyclist crash type	1,580	72.8%	590	27.2%	2,170	100.0%
Total	**2,118**	**73.9%**	**748**	**26.1%**	**2,866**	**100.0%**

Table 22: N and % of severe (K+A) Bicyclist crashes by crash type and location status. (Crash types with >=40 K+A bike crashes are shown separately, and the rest are combined in the final row)

Crash Type	KA Crashes off the HIN		KA Crashes on the HIN		Total	
	N	%	N	%	N	%
Stop - MV Forward - Bike Walk/Cycle Across Traffic/Roadway	36	81.8%	8	18.2%	44	100.0%
Signal - MV Forward - Bike Walk/Cycle Across Traffic/Roadway	22	52.4%	20	47.6%	42	100.0%
Other bicyclist crash type	150	69.4%	66	30.6%	216	100.0%
Total	**208**	**68.9%**	**94**	**31.1%**	**302**	**100.0%**

Like bicyclist crash types, pedestrian and other VRU crash types that occur at signalized intersections have the greatest representation on the network (Table 23 and Table 24). Segment/midblock and stop-controlled intersection crash types are less likely to happen on the HIN. The higher inclusion of signalized intersection crashes may reflect higher volumes and higher VRU activity at signalized intersections, as well as the general spatial clustering of signalized intersections in denser, urbanized areas. Among bicyclist crashes, crashes involving a driver going forward and the bicyclist crossing the roadway were much better captured by the HIN than crashes in which the driver was turning or the bicyclist was riding with or against traffic. The HIN best captures pedestrian signalized intersection crashes in which the driver was going forward or turning left. This finding has important implications for how the HIN is used, since we know the HIN captures signalized intersection crashes better than other crash types. Systemic network screening or other tools should be used in tandem with the HIN to help agencies target crash types that are poorly represented on the HIN.

Table 23: N and % of Pedestrian/VRU crashes by crash type and location status. (Crash types with >=40 K+A ped/VRU crashes are shown separately, and the rest are combined in the final row)

Crash Type	Crashes off the HIN		Crashes on the HIN		Total	
	N	%	N	%	N	%
Stop - MV Forward - Ped at intersection	572	73.5%	206	26.5%	778	100.0%
Segment - MV Forward - Ped Crossing	321	76.6%	98	23.4%	419	100.0%
Signal - MV Forward - Ped at intersection	232	43.2%	305	56.8%	537	100.0%
Segment - MV Forward - Ped Not Crossing	251	86.3%	40	13.7%	291	100.0%
Signal - MV Left - Ped at intersection	259	44.7%	320	55.3%	579	100.0%
Segment - MV Left/Right/Other/unknown	216	85.4%	37	14.6%	253	100.0%
Segment - MV Forward - Ped In Roadway - Other (working playing etc.)	84	84.8%	15	15.2%	99	100.0%
Other pedestrian/VRU crash type	1,050	70.7%	435	29.3%	1,485	100.0%
Total	**2,985**	**67.2%**	**1,456**	**32.8%**	**4,441**	**100.0%**

Table 24: N and % of severe (K+A) Pedestrian/VRU crashes by crash type and location status. (Crash types with >=40 K+A ped/VRU crashes are shown separately, and the rest are combined in the final row)

Crash Type	KA Crashes off the HIN		KA Crashes on the HIN		Total	
	N	%	N	%	N	%
Stop - MV Forward - Ped at intersection	148	66.4%	75	33.6%	223	100.0%
Segment - MV Forward - Ped Crossing	92	65.7%	48	34.3%	140	100.0%
Signal - MV Forward - Ped at intersection	48	35.8%	86	64.2%	134	100.0%
Segment - MV Forward - Ped Not Crossing	73	83.9%	14	16.1%	87	100.0%
Signal - MV Left - Ped at intersection	33	44.6%	41	55.4%	74	100.0%
Segment - MV Left/Right/Other/unknown	54	84.4%	10	15.6%	64	100.0%
Segment - MV Forward - Ped In Roadway - Other (working playing etc.)	47	87.0%	7	13.0%	54	100.0%
Other pedestrian/VRU crash type	166	70.9%	68	29.1%	234	100.0%
Total	**661**	**65.4%**	**349**	**34.6%**	**1,010**	**100.0%**

HIN Status by SPACE Score and Variables

We joined the High Injury Network to the SPACE dataset by flagging any hexagon that intersects with any HIN segment. Overall, there were 868 hexagons out of 522,263 that contained any of the HIN, or about 0.2% of the state (Table 25). The HIN is concentrated in hexagons with medium and high SPACE suitability scores, with the greatest concentration in the 70-74 and 75-79 score range (34% and 39% respectively).

Table 25. Presence of HIN by SPACE score

SPACE Suitability Score	Hexagons with 1+ HIN segments	Hexagons with no HIN segments	Percentage of hexagons with 1+ HIN segments
0-39	49	302,093	0%
40-44	57	110,965	0.1%
45-44	152	62,227	0.2%
50-54	144	32,213	0.4%
55-59	135	10,404	1.3%
60-64	104	2,672	3.7%
65-69	108	601	15.2%
70-74	68	130	34.3%
75-79	40	63	38.8%
80-100	11	27	28.9%
Total	**868**	**521,395**	**0.2%**

The HIN is over-represented among hexagons where 50% or more of residents are People of Color. Just under 1% of hexagons where 50% or more of residents are POC and 40% or more are low income contain HIN segments. Where residents are majority POC and less than 40% low income, about 2.5% of hexagons contain HIN. These represent a 4-fold and 15-fold over-representation, respectively, relative to the state at large.

Table 26. Presence of HIN by SPACE equity variables – areas of concentrated poverty and areas where 50% or more of residents are People of Color

SPACE Equity Variables (income and race/ethnicity)	Hexagons with 1+ HIN segments	Hexagons with no HIN segments	Percentage of hexagons with 1+ HIN segments
At least 40% low income - At least 50% POC	71	10,087	0.7%
Less than 40% low income - At least 50% POC	4	157	2.5%
At least 40% low income - Less than 50% POC	63	35,631	0.2%
Less than 40% low income - Less than 50% POC	730	475,520	0.2%
Total	**868**	**521,395**	**0.2%**

Conclusions and Next Steps

This analysis produced a statewide HIN that captures about 30% of Minnesota's total VRU crashes. There is considerable variation by geography, year, mode, and severity regarding which crashes are well represented on the HIN and which are more dispersed. The HIN best captures signalized intersection crashes in major urban areas, though smaller urban areas are also represented. Reflecting underlying inequities in who bears the burden of VRU crashes, the HIN is relatively more concentrated in majority-POC neighborhoods.

The HIN is one of many tools to assist MnDOT and local agencies with planning and engineering for VRU safety. The HIN itself can help communities identify segments with the greatest concentration of crashes needing further investigation and safety improvements. Communities may also access the underlying sliding windows data, if they wish to identify their own threshold and local HIN. Systemic and predictive analyses can also be used to screen both the HIN and other streets for risk factors.

The project team is working to assemble a data dashboard visualizing the High Injury Network alongside other crash trends and patterns. Our next steps are to finalize the systemic analysis and bring together findings and recommendations.

Future updates to the VRUSA should explore patterns over time around the COVID-19 pandemic, once more years of post-pandemic crash data are available.